Hycom Consortium for Data Assimilative Ocean Modeling

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LONG-TERM GOALS

Development of a consortium for hybrid-coordinate data assimilative ocean modeling, which will be ready in 2003 to address both the US-GODAE (Global Ocean Data Assimilation Experiment) principal objective, i.e., the depiction of the three-dimensional ocean state at fine resolution in near-real time, and the climate modeling objective of producing an unbiased estimate of the state of the ocean at coarse resolution for long-term climate variability research.

This effort is part of a 5-year (FY00-04) multi-institutional National Ocean Partnership Program (NOPP) project which includes E. Chassignet (coordinator), G. Halliwell, and A. Mariano (U. of Miami/RSMAS), M. Chin (JPL/U. of Miami), R. Bleck (LANL), H. Hurlburt, A. Wallcraft, P. Hogan, R. Rhodes, C. Barron, and G. Jacobs (NRL-Stennis), O.M. Smedstad (Planning Systems, Inc.), W.C. Thacker (NOAA/AOML), and Remy Baraille (SHOM).

OBJECTIVES

The primary objective is the establishment of a global real-time ocean forecast system based on a hybrid-coordinate ocean model with sophisticated data assimilation techniques that can be efficiently executed on massively parallel computers.

APPROACH

- Hierarchy of model configurations from fully global to regional/coastal

- Coarse resolution model-based reanalysis of archived observational data will provide a comprehensive picture of the dynamics and thermodynamics of the global ocean during recent decades;

- Expertise on the model's behavior with an eddy-resolving grid will be gained by running the model in basin-scale configurations using lateral boundary conditions provided by the global simulations.

- Sophisticated data assimilation techniques

WORK COMPLETED

a) Release of HYCOM 2.1

b) Global, basin-scale, and regional simulations

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14. ABSTRACT
Development of a consortium for hybrid-coordinate data assimilative ocean modeling, which will be ready in 2003 to address both the US-GODAE (Global Ocean Data Assimilation Experiment) principal objective, i.e., the depiction of the three-dimensional ocean state at fine resolution in near-real time, and the climate modeling objective of producing an unbiased estimate of the state of the ocean at coarse resolution for long-term climate variability research.

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c) Data assimilation capabilities

RESULTS

The HYCOM Consortium for Data Assimilative Ocean Modeling is a multi-institution effort and this report mostly focuses on work that was performed at the University of Miami or in collaboration with scientists at the partnering institutions. The reader is referred to the complementary reports of H. Hurlburt (NRL), O.M. Smedstad (Planning Systems, Inc.), and C. Thacker (NOAA) for a complete overview of the NOPP-funded effort.

Traditional vertical coordinate choices [z-level, terrain-following (sigma), isopycnic] are not by themselves optimal everywhere in the ocean, as pointed out by recent model comparison exercises performed in Europe (DYnamics of North Atlantic MOdels - DYNAMO) and in the U.S. (Data Assimilation and Model Evaluation Experiment - DAMEE). Ideally, an ocean general circulation model (OGCM) should (a) retain its water mass characteristics for centuries (a characteristic of isopycnic coordinates), (b) have high vertical resolution in the surface mixed layer (a characteristic of z-level coordinates) for proper representation of thermodynamical and biochemical processes, (c) maintain sufficient vertical resolution in unstratified or weakly-stratified regions of the ocean, and (d) have high vertical resolution in coastal regions (a characteristic of terrain-following coordinates).

The hybrid coordinate adopted in HYCOM (HYbrid Coordinate Ocean Model) is one that is isopycnal in the open, stratified ocean, but smoothly reverts to a terrain-following coordinate in shallow coastal regions, and to pressure-level coordinates in the mixed layer and/or unstratified seas. The hybrid coordinate extends the geographic range of applicability of traditional isopycnic coordinate circulation models (the basis of the present hybrid code), such as the Miami Isopycnic Coordinate Ocean Model (MICOM) and the Navy Layered Ocean Model (NLOM), toward shallow coastal seas and unstratified parts of the world ocean [see Bleck (2002) for details].

The lastest version of HYCOM (version 2.1) was recently released (September 2002) and is the result of collaborative efforts between the Naval Research Laboratory (Wallcraft), the University of Miami (Halliwell), and the Los Alamos National Laboratory (Bleck). A major aspect of this new release is that the standard version of HYCOM is now ready for application as a fully global ocean model: Halos were added for MPI to automatically support periodic boundaries and the capability to handle orthogonal curvilinear grids was added and used to create a bi-polar (PanAm) grid to cover the northern polar region. The latter matches the spherical grid convering the remainder of the global ocean at 47°N. Other additions to HYCOM 2.1 include support for nested-domain open boundaries, Mellor-Yamada 2.5 (Mellor and Yamada, 1982) and Price-Weller-Pinkel (Price et al., 1986) as new embedded mixed layer options, support for multiple tracers, and NetCDF output files (see http://hycom.rsmas.miami.edu for details).

The capability of assigning additional coordinate surfaces to the oceanic mixed layer in HYCOM gives us the option of implementing sophisticated vertical mixing turbulence closure schemes. Halliwell (2002) evaluated the vertical mixing algorithms embedded in HYCOM using low-resolution climatological simulations of the Atlantic Ocean. Thirteen model experiments were analyzed involving different combinations of vertical mixing algorithms, vertical coordinate choice, and vertical resolution. The basic set of eight experiments was run with 22 vertical layers. Seven of these were run with hybrid vertical coordinates to evaluate sensitivity to vertical mixing choice while the other was run with isopycnic coordinates (MICOM mode) to determine sensitivity to vertical coordinate choice.

To complete the set of experiments, five of the 22-layer experiments were re-run with 32 vertical layers to evaluate the impact of vertical resolution.

The full set of vertical mixing options contained in the latest version of HYCOM (version 2.1) includes six primary vertical mixing algorithms, of which two are non-slab models and four are slab models. The two non-slab models govern vertical mixing throughout the water column and are the nonlocal K-Profile Parameterization model of Large et al. (1994) (KPP), and the level 2.5 turbulence closure algorithm of Mellor and Yamada (1982) (MY). The slab models include the dynamical instability model of Price et al. (1986) (PWP) and three versions of the Kraus-Turner model. There are two versions of the Kraus-Turner model to be used with hybrid vertical coordinates: an accurate (but relatively inefficient) version (KTA) along with a simplified (less accurate, but more efficient) version (KTB). The KTB model was used in the global simulation of Bleck (2002). A third version of the Kraus-Turner model (KTC) obtained from MICOM 2.8 is used when the model is run with isopycnic vertical coordinates only (MICOM mode). Since the four slab models govern only mixed layer entrainment and detrainment, three interior diapycnal mixing algorithms are also included in HYCOM to supplement these mixed layer models. Two of these are designed for use with hybrid vertical coordinates, an explicit (MICOM-like) model and an implicit (KPP-like) model. Implementation of these vertical mixing algorithms in HYCOM required the addition of penetrating shortwave radiation and of an implicit solution algorithm for the vertical diffusion equation. An alternative to the KPP algorithm, proposed by Canuto (2001), was also implemented in HYCOM 2.0 by post-doctoral associate A. Romanou and is presently under evaluation.

HYCOM 2.0 has been configured globally, on basin scales, and regionally. The fully global configuration (present resolution of .72^{o}) is currently being integrated by J. Metzger (NRL). Coupling of the fully global configuration (resolution of 2^{o}) to an atmospheric model has been performed by R. Bleck (Los Alamos) and S. Sun (NOAA). Coupling to an ice model is underway and is being evaluated by D. Bi (RSMAS). The North Pacific basin-scale simulations are based on simulations previously performed with NLOM (see H. Hurlburt's report for details). The North Atlantic basin-scale simulations are based on the Community Modeling Experiment (CME), DYNAMO, and MICOM experiences (1^{o}, 1/3^{o}, and 1/12^{o} grid spacing, respectively).

The series of North Atlantic CME-like experiments investigates the impact of the vertical coordinate choice and resolution, reference density, and thermobaricity. We first compared the HYCOM results to those from MICOM with identical basin configuration, forcing, and lateral boundary conditions. We then focused on determining the effect of the coordinate representation of density (σ_θ, $\sigma2$, $\sigma2$ with thermobaricity) on the model's ability to accurately represent the water mass distributions and three-dimensional circulation of the Atlantic. In Chassignet et al. (2002), the hybrid model's performance is evaluated by comparison to observations and to previous simulations configured for the North and Equatorial Atlantic. Building on past studies with the Community Modeling Experiment (CME) configuration (Chassignet et al., 1996; Smith et al., 2000), we examined the effect of the coordinate choice(s) on the model's ability to accurately represent the water mass distributions and three-dimensional circulation of the Atlantic. We performed several single-coordinate experiments, not only to illustrate the flexibility of the model, but also to bring forth some of the limitations associated with such a choice. Pure z-coordinate simulations showed the behavior described in Chassignet et al. (1996) for z-coordinate models, i.e. a warming of the deep ocean. MICOM mode simulations showed that the weak vertical discretization in unstratified regions did not permit a proper representation of the mixed layer physics. We addressed also one specific issue which is present in models such as MICOM or HYCOM that employ potential density either as the sole vertical coordinate or as one component of the hybrid framework: the question of how best to represent the potential density distribution

throughout the entire oceanic depth range for a given reference pressure. The series of experiments demonstrated that a reference pressure at 2000 dbar indeed allow for a correct representation of the dense water masses that originate in Antarctica. When a reference pressure at the surface is used (sigma-theta), these water masses are characterized by an inversion in the vertical potential density profile which cannot be modeled. The addition of thermobaricity allowed us to quantify its importance on the surface and deep ocean circulations.

The NRL group has run several 1/3^o Atlantic simulations, including climatological and interannual with high frequency atmospheric forcing and HYCOM mode vs MICOM mode. HYCOM 2.0 bundled with a 1/3^o degree Atlantic simulation is our official test bed for use in data assimilation development and evaluation. It is available from the HYCOM web site and is presently being used by data assimilation consortium members O.M. Smedstad (PSI), R. Baraille (SHOM), P. Brasseur (LEGI), and M. Chin (RSMAS).

The 1/12^o HYCOM Atlantic domain is a major component of our HYCOM effort since the ultimate goal is a transition to a 1/12^o global ocean prediction system in 2006. In close collaboration with H. Hurlburt's group, the first 1/12^o Atlantic HYCOM simulation was initialized from the latest 1/12^o MICOM simulation, which has a very good Gulf Stream pathway (Figure 1). The domain is the North and Equatorial Atlantic Ocean basin from 28^{o}S to 70^{o}N, including the Caribbean Sea, the Gulf of Mexico, and the Mediterranean Sea. The horizontal grid (6 km on average) is defined on a Mercator. The bottom topography is derived from the 5' ETOPO5 digital terrain. Open ocean boundaries are treated as closed, but are outfitted with 3^o buffer zones in which temperature and salinity are linearly relaxed toward their seasonally varying climatological values, with damping/relaxation time from 5 days at the wall to 30 days at the inner edge of the buffer zone. These buffer zones restore the vertical shear of the currents at the boundaries through geostrophic adjustment. The surface salinity forcing is a combination of evaporation-precipitation from COADS climatology and relaxation to the Levitus sea surface salinity climatology. Ice is included via a simple energy loan model.

During FY02, an FY02-04 DoD HPC Challenge project was used to run 1/12° Atlantic HYCOM for a period of 8.4 years in a sequence of 3 experiments, 2+ years with monthly climatological ECWMF forcing, 3 years with 6-hourly high frequency monthly climatological forcing and July 1999 - July 2002 with 3 or 6 hourly hybrid Fleet Numerical Meteorology and Oceanography Center (FNMOC)/ECMWF forcing, where the FNMOC mean wind stress over 1990-2001 is replaced by the ECMWF reanalysis mean. As mentioned above, the first of these HYCOM simulations was initialized from the best 1/12° MICOM Atlantic simulation and the other two from the preceding experiment. The first experiment was set up to emulate the MICOM experiment as closely as possible. O.M. Smedstad (PSI) is using the July 1999-July 2002 Atlantic HYCOM simulation to initialize a data-assimilative 1/12° Atlantic HYCOM run (see his ONR report for more details). In close collaboration with the NRL group, we are presently evaluating this simulation by comparing the model results to observations and to the companion MICOM simulation (see H. Hurburt ONR report for more details).

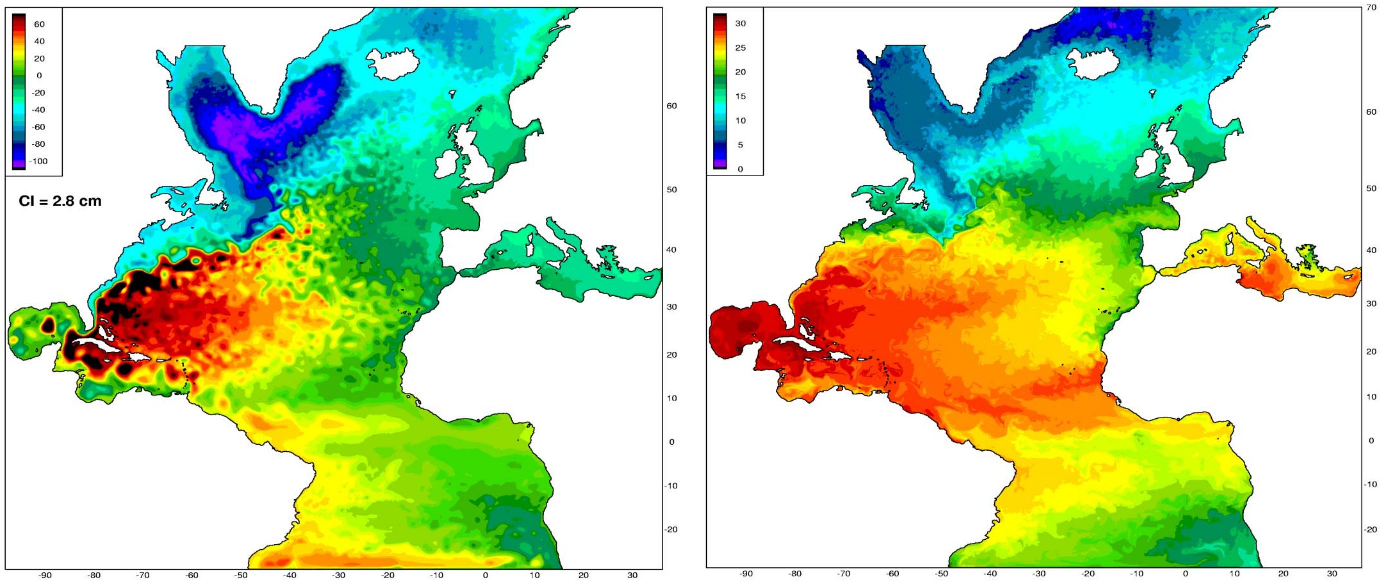

Fig. 1: Snapshots of the 1/12^{o} HYCOM after being initialized from the latest ECMWF MICOM run. Left panel: Sea surface height. Right Panel: Sea surface temperature.

For assimilation of surface altimetry data, the Reduced Order Information Filter (ROIF) has been ported from MICOM to the HYCOM coordinate system. ROIF is a reduced order implementation of Kalman filter that has been shown (Chin et al., 1999; 2001) to be effective in observation system simulation experiments (twin experiments) for assimilation of sea surface heights sampled sparsely as in the Topex/Poseidon satellite. The assimilation technique has also been proven mathematically to preserve positive definiteness in the approximated covariance matrix (Chin, 2001).

Porting of ROIF assimilation system from MICOM to HYCOM is achieved by converting its vertical axis from one that based on layer-thickness to a pressure-based coordinate. The HYCOM-adapted ROIF was tested first in a 2^{o} x 2^{o} grid model of North Atlantic with the KPP mixing scheme. Preliminary analysis show that the sea surface height field converges exponentially towards the truth (a twin run) through assimilation of the sparsely sampled (TOPEX/Poseidon track) data. This result is consistent with the previous performance with MICOM.

Further evaluation of the HYCOM-adapted ROIF is underway. Our agenda is to perform (i) quality checks of the new ROIF numerics, e.g., matrix conditioning, (ii) an evaluation of the vertical profiling and its sensitivity to the prior/empirical statistics, (iii) an evaluation with the finer resolution HYCOM, i.e., 1/3^{o} North Atlantic configuration.

In addition to ROIF, the consortium is evaluating an Optimal Interpolation (OI) scheme combined with a Cooper-Haines vertical projection of the surface information (put in place by O.M. Smedstad and R. Baraille); (2) the Reduced Order Adaptive Filter (ROAF) (Hoang et al., 1997), which estimates unknown parameters by minimizing the forecast error; this technique requires the model's adjoint (developed and parallelized by R. Baraille); and (3) the Single Evolutive Extended Kalman (SEEK) filter (in collaboration with P. Brasseur and J. Verron);.

At the present time, only the Cooper and Haines (1996) OI scheme has been implemented in the 1/12° North Atlantic configuration. The SEEK filter has been ported to the 1/3° North Atlantic configuration and is under evaluation. Both the ROAF and ROIF are being transitioned to the same configuration. The four data assimilation schemes will then be evaluated in parallel and on the same footing against observations in a series of near-real-time data assimilation experiments. G. Evensen, one of our NOPP collaborator, will be participating in this evaluation exercise with his HYCOM Ensemble Kalman Filter which is already operational in the North Atlantic (http://www.nrsc.no/~geir/hycomstuff.html).

Finally, a strong component of our HYCOM initiative is web outreach. A critical problem in ocean modeling and data assimilation is making both the observational data and model output available to (a) the members of our consortium for HYCOM and data assimilation code development, (b) the wider oceanographic and scientific communities, including climate and ocean ecosystem researchers; and (c) the general public (especially students in elementary and high school). For that purpose, a Live Access Server (LAS) has been installed in Miami. LAS was developed a group of scientists at NOAA-PMEL and is a highly configurable Web server designed to provide flexible access to geo-referenced scientific data. It enables the Web user to visualize data with on-the-fly graphics, request custom subsets of variables in a choice of file formats, access background reference material about the data (metadata), and compare (difference) variables from distributed locations. A. Srinivasan (U. of Miami) is in charge of maintaining the server (for more details, see separate ONR report by E. Chassignet). A. Mariano is putting together a Web-based reference site on ocean currents (Mariano et al., 2002).

IMPACT/APPLICATIONS

Generation of optimal estimates of the time-varying ocean state in support of the NAVY's needs on synoptic time scales on the order of weeks to months and on spatial scales typically on the order of 10-1000 km (mesoscale).

TRANSITIONS

None

RELATED PROJECTS

This effort is part of a multi-institutional NOPP project which includes E. Chassignet (Coordinator), G. Halliwell, and A. Mariano (U. of Miami/RSMAS), T. Chin (JPL/U. of Miami), R. Bleck (LANL), H. Hurlburt, A. Wallcraft, P. Hogan, R. Rhodes, C. Barron, and G. Jacobs (NRL-Stennis), O.M. Smedstad (Planning Systems, Inc.), W.C. Thacker (NOAA/AOML), P. Brasseur (LEGI), and R. Baraille (SHOM).

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